

DATA HARVESTING

With visions of plenty, Los Alamos is helping farmers in Northern New Mexico use science to improve their strategy against damaging frosts.

“THE APPLE SUPPLY IN NORTHERN NEW MEXICO ISN’T AS RELIABLE AS ONE WOULD LIKE,” says Los Alamos electrical engineer Gary Goddard. In his free time, Goddard ferments apple juice with his friend Mike Steinzig, a weapons engineer who has been making hard cider for the past 19 years. Gathering apples from a variety of local sources, they usually make nearly 100 gallons a season, but a plentiful apple harvest at any given farm only happens in about one out of every three years. On the surface, the problem is that late spring frosts kill the apple blossoms. But the real problem is that unseasonably warm days in the middle of winter cause the trees to bloom too early.

Although some people might delight in a 60-degree sunny day in January, farmers (and skiers) do not. Plants need cold weather; it is part of their annual cycle of dormancy, growth, and fruiting. Too many warm days during the winter months might encourage a plant to bud early, and when the frosts return in late spring—as they always do—the buds can freeze and fail to produce fruit. A smaller or nonexistent apple crop might be a mere disappointment for Goddard and Steinzig’s cider-making hobby, but for a farmer whose livelihood depends on the harvest, frost damage can be devastating.

“The last five years have been really disheartening—to see all the blossoms and potential fruit and then one night it’s gone,” says Tim Seaman, who owns the **Manzanar Los Silvestres apple orchard** in Abiquiú, New Mexico.

In an effort to help farmers facing this annual challenge, Goddard and Steinzig have been leveraging expertise from their day jobs to analyze the frost problem and improve crop protection for Seaman and other growers in Northern New Mexico. Since 2017, the Lab team has been monitoring variables such as temperature, humidity, and wind at each farm and is now beginning to make recommendations. The scientists aim to help farmers mitigate frost damage by making informed decisions—based on each farm’s





Hydrologist Kurt Solander downloads temperature and humidity data from various instruments situated inside a greenhouse at the Freshies of New Mexico farm in Lyden. *PHOTO CREDIT: Michael Pierce*

unique microclimate—about how and when to protect their crops. The goal is to use data to implement the right strategy for each farm and to deploy a low-cost, easy-to-use sensor system to give growers real-time warnings during the critical spring weeks when their crops are most vulnerable.

Fire and ice

Created as a partnership between the State of New Mexico and the national labs, the New Mexico Small Business Assistance program (NMSBA) provides unique technical expertise to small businesses facing complex challenges. Businesses apply for assistance from the NMSBA program (<https://www.nmsbaprogram.org>), which uses a state tax credit to enable Laboratory participation. In 2017, when two farm owners—Seaman along with Christopher Bassett of Freshies of New Mexico in Lyden—approached the NMSBA with concerns about protecting their crops from frost, the organization requested that Steinzig, Goddard, and their colleagues tackle the problem. The NMSBA funding allows the scientists to examine frost-mitigation methods, to study how frost moves across varied terrain, and ultimately to provide individualized data-based recommendations for each farm to improve frost protection.

“The NMSBA was created to promote economic development in rural areas, and agriculture is a big piece of that,” says Julia Wise, a project manager for the NMSBA. With this in mind, the organization stepped in to help the farmers, for whom frost protection is a priority in order to ensure consistent, dependable crops each year.

“When the trees are flowering, a 28-degree night could result in a 10 percent loss of fruit,” says Bassett. “But just a few degrees colder, say 24 degrees, could make it more like a 90 percent loss.” Freshies of New Mexico is Bassett’s family business; he and his wife operate two farms in the Española valley in Northern New Mexico. Faced with a daunting frost risk each season, Bassett has put a significant amount of time and money into infrastructure for frost protection. By working with Los Alamos, Bassett hopes to optimize his approach and get the most out of his investments.

At one of Bassett’s farms, he uses sprinklers to protect the crops by coating

the plants with a layer of ice on cold nights just before the frost comes. This process works because heat is released as a result of the ice formation; that heat is called the latent heat of solidification. However, this approach only works within a narrow range of temperature and wind conditions, so Bassett has been looking into other strategies. His largest investment has been to build 12 heated greenhouses (each one with a 31 × 300-foot area) at his second farm where he grows everything from tomatoes and chiles to peaches and apples.

On cold nights, farmer Christopher Bassett of Freshies of New Mexico occasionally sprays water on his apple blossoms to protect them because heat is released as the water turns to ice—the latent heat of solidification. This is one of many strategies farmers use to protect their crops during the springtime when their plants are most vulnerable. PHOTO CREDIT: Taylor Dale Bassett



“Some folks think I’m nuts to try this,” says Bassett, referring to the fact that it is unusual to plant an entire orchard of fruit trees inside a greenhouse.

Not everyone, however, has the capital to invest in heated greenhouses or sprinkler systems. For centuries, many farmers have fought frosts using a variety of other methods, including covering their crops to insulate them and even staying up all night to maintain small bonfires in their fields to keep the area warm. Seaman, whose small orchard grows specialty apples for local cider makers, says he is not able to make a large capital investment—like a heating system or greenhouse—and would like to explore less expensive options for frost protection. Seaman has tried coating his apple blossoms with ice and also has used fans to prevent the cold air from settling around the trees, but with minimal success.

Large investment or small, the questions still abound: How do farmers know when to light the fires or turn on the heaters or sprinklers? And for how long? Where is the best location for a fan to mix the air, and what other strategies could be used? The farmers would benefit from knowing which investments are most suited to their own farms and how best to use them—and this is where the scientists come in.



Plump peaches are a sign of success. Every spring, farmers in New Mexico worry that frosty nights might kill their trees' blossoms and eliminate the possibility of growing fruit, like these peaches at Freshies of New Mexico. Monitoring air temperature using the sensor shown here is one of the ways that Los Alamos scientists have been helping farmers optimize their strategies to protect crops from frost. *PHOTO CREDIT: Michael Pierce*

Plentiful data

The project began with Steinzig enlisting the help of hydrologist Kurt Solander and postdoctoral atmospheric scientist Tirtha Banerjee to look at the terrain of each farm and to try to understand what frost mitigation techniques would be possible. With help from plant physiologist

Sanna Sevanto, they also set up wired instrumentation around each farm to gather an assortment of data. However, the cost and difficulty of maintaining the instrumentation quickly became apparent as the scientists had to drive to the farms to manually download the data and the farmers found the wires to be both a tripping hazard and easily broken. A search began for a more cost-effective, networked, and self-sustaining data-gathering option. Goddard put his experience with wireless data sensors to work, and with renewed funding in 2018 and 2019, he worked with electrical engineering graduate student Josh Sackos to implement wireless sensors to remotely monitor a wide range of variables.

"It's not enough just to know the temperature," says Banerjee. "There are a lot of factors at play that impact a plant's vulnerability to frost."

For one, when plants are dormant in the winter, they actually need the weather to get cold, a requirement referred to as "chill hours." Each plant requires a different temperature range and number of chill hours in order to flourish in the spring, and plants that don't get the appropriate amount are shown to be less robust against frosts. Moisture is also important; sufficient soil moisture and plant-tissue moisture are needed to help the plant resist damage.

With all of this in mind, the Los Alamos scientists set out to measure everything they could: air temperature, wind speed and direction, soil moisture, plant tissue temperature and moisture, relative humidity, and light availability. They also took into consideration the varied conditions at and around each individual farm and began to make recommendations to the farmers as soon as they could.

For instance, at Freshies, the scientists looked at the placement of the thermostat used to trigger the heating system within the greenhouses. Once they could identify which area got cold first, they recommended that Bassett move the thermostat to that particular spot so the heaters were triggered before the temperature drops to dangerous levels for crops within the greenhouse.

After analyzing temperature data with the heaters turned on for a couple of weeks, the team also recommended to Bassett that he adjust the heaters to start when the temperature reaches 32 degrees Fahrenheit instead of 30. This was done to provide more of a buffer against crop damage that occurs when temperatures drop below 28 degrees. However, Solander also explains that although the difference of a few degrees can cause a lot of damage, if the heaters go on too early or if heat is lost, it can waste energy, which can be prohibitively costly. To this end, the scientists determined the most vulnerable locations within the greenhouse, so that Bassett could address air leaks and circulation patterns within the structure of the greenhouse.

Because there are no greenhouses or heating systems at the Manzanar orchard, the Los Alamos team focused on understanding the impact of the local topography. Seaman had already pruned vegetation in an attempt to redirect cool air coming down from a nearby mesa in order to keep it away from the farm. Solander distributed sensors around the orchard and also used a drone to better understand the stratification of air temperatures over the area. The combined sensor and drone data characterized vertical and horizontal temperature gradients that were variable through time, and Solander hopes that more densely distributed and

**When the trees are flowering,
a 24-degree night results
in 90 percent loss.**

continuously monitored measurements in 2019 will help them refine conclusions about cold air mitigation.

To further understand the microclimate, the team used a Los Alamos-developed software tool called HIGRAD to model the airflow coming down from the mesa. Using atmospheric dynamics simulations, Banerjee suggests that they may be able to better understand the air mixing. Solander adds that by combining the modeled data with temperature measurements, they hope to simulate the efficacy of potential low-cost solutions, such as planting a row of 10–15-meter tall trees to act as a windbreak to protect the apple trees.

Seeking signal strength

Although the scientists have been able to make a few recommendations to the farmers thus far, one of the challenges the team has faced is a lack of consistency in data collection due to equipment malfunctions. In an effort to keep costs down, the team used off-the-shelf sensors that were each capable of sending data independently over a 3G cellular network for remote analysis. However, the cellular signal that worked with the sensors had intermittent coverage at the rural farms, and the data acquisition was spotty at best.

Fortunately, as the team began to investigate alternatives, a different kind of sensor became more widely available, and at a reasonable price. Using these new sensors, Sackos and Goddard established a platform for the 2019 season that works as a low-power wireless mesh network. With this network, the distributed sensors are connected to each other and to a central sensor that uses either Wi-Fi or LTE cellular signal to transmit the data to cloud-based storage. The data can then be pulled down into a database for analysis by Solander and Banerjee.

"We want to leave farms with an easy way to implement these hardware and software solutions in the future," explains Sackos. He says that by using commercially available hardware and open-source software, the system could be implemented at any farm. For instance, if a new farm were to join the program, the Los Alamos scientists could first help by analyzing the individual microclimate to provide recommendations about which mitigation strategies are appropriate (heaters,

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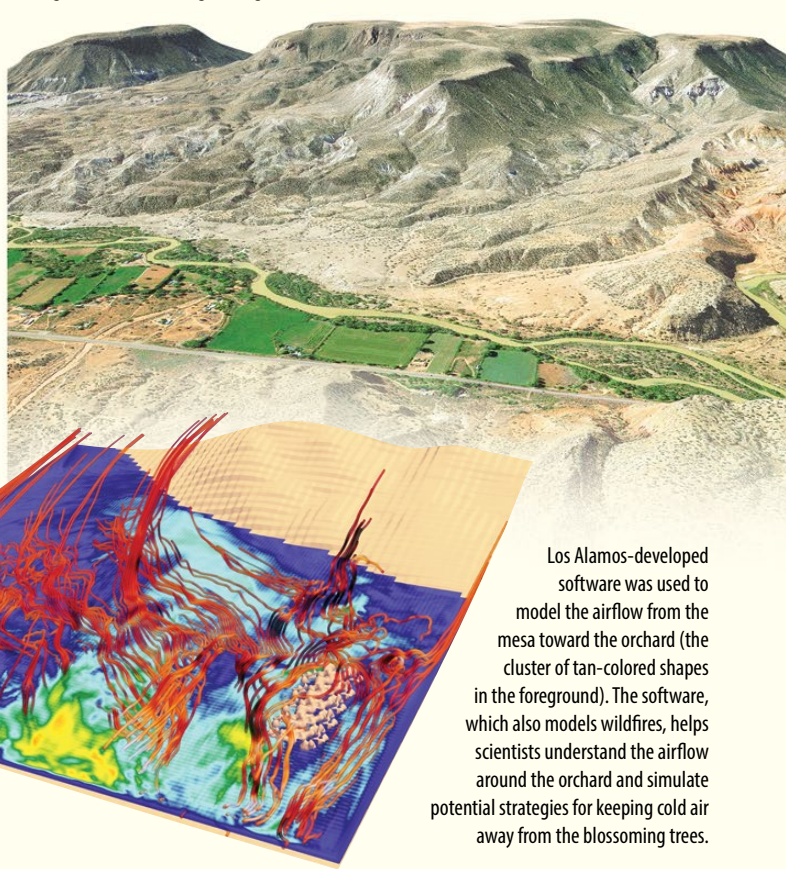
windbreaks, etc.). Once in place, a farmer could invest in sensors to connect to an entire regional network of farms, all working together to help track impending frost conditions, which could enable alerts to be sent when the temperature hits a critical point.

As word has spread about the network, interest in the project has grown. A third farmer, Sam Starsiak from the Diamond Sow farm in Truchas, New Mexico, has already requested support in monitoring soil moisture, and others are lining up.

Love locally grown

Using technology to help warn about or mitigate frost damage could have an immediate benefit for local farms in Northern New Mexico. Banerjee explains that this kind of data collection and intervention, or "smart agriculture," is becoming more and more common

The Manzanar Los Silvestres apple orchard is nestled against the Rio Chama river near the town of Abiquiu. It is a difficult place to grow apples in part because of cold air flowing down from the neighboring mesa. *IMAGE CREDIT: Google, Landsat / Copernicus*



Los Alamos-developed software was used to model the airflow from the mesa toward the orchard (the cluster of tan-colored shapes in the foreground). The software, which also models wildfires, helps scientists understand the airflow around the orchard and simulate potential strategies for keeping cold air away from the blossoming trees.

with industrial agriculture, but at a hefty price. He hopes that the Los Alamos-NMSBA approach to helping smaller farms with less-expensive alternatives will keep them competitive, thus strengthening local agriculture as a whole. But for the farmers and consumers, the state economy isn't the only reason to support local produce.

"I came to farming through food. I was captivated by how good fresh food can taste," says Bassett.

Bassett explains that when fruits and vegetables are transported long distances between farm and grocery store, they have to be picked before they are ripe and sometimes stored for long periods of time. Allowing food to ripen "on the vine" allows it to develop and retain a significant amount of flavor and nutrients. Local food also has a smaller impact on the environment compared to industrial agriculture where fossil fuel-based synthetic fertilizers and agrochemicals are commonplace and fossil fuels are used to operate farm machinery and transport food long distances.

For these reasons, Bassett and Seaman provide a wide variety of fruits and vegetables to nearby stores and restaurants. They also sell their goods directly to customers at regional farmers' markets. And even as the growing season shifts, they'd like to keep their produce the same as it has always been: fresh, sustainable, and local.

—Rebecca McDonald